

GaAs, AgCaSe₂, ZnSe, GaP, InP, ZnS, and combinations comprising at least one of the foregoing.

[0056] Exemplary variable modulus materials also comprise magnetorheological (MR) and ER polymers. MR polymers are suspensions of micrometer-sized, magnetically polarizable particles (e.g., ferromagnetic or paramagnetic particles as described below) in a polymer (e.g., a thermoset elastic polymer or rubber). Exemplary polymer matrices include poly- α -olefins, natural rubber, silicone, polybutadiene, polyethylene, polyisoprene, and combinations comprising at least one of the foregoing.

[0057] The stiffness and potentially the shape of the polymer structure are attained by changing the shear and compression/tension moduli by varying the strength of the applied magnetic field. The MR polymers typically develop their structure when exposed to a magnetic field in as little as a few milliseconds, with the stiffness and shape changes being proportional to the strength of the applied field. Discontinuing the exposure of the MR polymers to the magnetic field reverses the process and the elastomer returns to its lower modulus state. Packaging of the field generating coils, however, creates challenges.

[0058] Electronic electroactive polymers (EAPs) are a laminate of a pair of electrodes with an intermediate layer of low elastic modulus dielectric material. Applying a potential between the electrodes squeezes the intermediate layer causing it to expand in plane. They exhibit a response proportional to the applied field and can be actuated at high frequencies. EAP morphing laminate sheets have been demonstrated. Their major downside is that they require applied voltages approximately three orders of magnitude greater than those required by piezoelectrics.

[0059] Electroactive polymers include those polymeric materials that exhibit piezoelectric, pyroelectric, or electrostrictive properties in response to electrical or mechanical fields. An example of an electrostrictive-grafted elastomer with a piezoelectric poly(vinylidene fluoride-trifluoro-ethylene) copolymer. This combination has the ability to produce a varied amount of ferroelectric-electrostrictive molecular composite systems.

[0060] Materials suitable for use as an electroactive polymer may include any substantially insulating polymer and/or rubber that deforms in response to an electrostatic force or whose deformation results in a change in electric field. Exemplary materials suitable for use as a pre-strained polymer include silicone elastomers, acrylic elastomers, polyurethanes, thermoplastic elastomers, copolymers comprising PVDF, pressure-sensitive adhesives, fluoroelastomers, polymers comprising silicone and acrylic moieties (e.g., copolymers comprising silicone and acrylic moieties, polymer blends comprising a silicone elastomer and an acrylic elastomer, and so forth).

[0061] Materials used as an electroactive polymer can be selected based on material property(ies) such as a high electrical breakdown strength, a low modulus of elasticity (e.g., for large or small deformations), a high dielectric constant, and so forth. In one embodiment, the polymer can be selected such that it has an elastic modulus of less than or equal to about 100 MPa. In another embodiment, the polymer can be selected such that it has a maximum actuation pressure of about 0.05 megapascals (MPa) and about 10 MPa, or, more specifically, about 0.3 MPa to about 3 MPa. In another embodiment, the polymer can be selected such that it has a dielectric constant of about 2 and about 20, or, more specifi-

cally, about 2.5 and about 12. The present disclosure is not intended to be limited to these ranges. Ideally, materials with a higher dielectric constant than the ranges given above would be desirable if the materials had both a high dielectric constant and a high dielectric strength. In many cases, electroactive polymers can be fabricated and implemented as thin films, e.g., having a thickness of less than or equal to about 50 micrometers.

[0062] As electroactive polymers may deflect at high strains, electrodes attached to the polymers should also deflect without compromising mechanical or electrical performance. Generally, electrodes suitable for use can be of any shape and material provided that they are able to supply a suitable voltage to, or receive a suitable voltage from, an electroactive polymer. The voltage can be either constant or varying over time. In one embodiment, the electrodes adhere to a surface of the polymer. Electrodes adhering to the polymer can be compliant and conform to the changing shape of the polymer. The electrodes can be only applied to a portion of an electroactive polymer and define an active area according to their geometry. Various types of electrodes include structured electrodes comprising metal traces and charge distribution layers, textured electrodes comprising varying out of plane dimensions, conductive greases (such as carbon greases and silver greases), colloidal suspensions, high aspect ratio conductive materials (such as carbon fibrils and carbon nanotubes, and mixtures of ionically conductive materials), as well as combinations comprising at least one of the foregoing.

[0063] Exemplary electrode materials can include graphite, carbon black, colloidal suspensions, metals (including silver and gold), filled gels and polymers (e.g., silver filled and carbon filled gels and polymers), and ionically or electronically conductive polymers, as well as combinations comprising at least one of the foregoing. It is understood that certain electrode materials may work well with particular polymers and may not work as well for others. By way of example, carbon fibrils work well with acrylic elastomer polymers while not as well with silicone polymers.

[0064] Magnetostrictives are solids that develop a large mechanical deformation when subjected to an external magnetic field. This magnetostriction phenomenon is attributed to the rotations of small magnetic domains in the materials, which are randomly oriented when the material is not exposed to a magnetic field. The shape change is largest in ferromagnetic or ferromagnetic solids. These materials possess a very fast response capability, with the strain proportional to the strength of the applied magnetic field, and they return to their starting dimension upon removal of the field. However, these materials have maximum strains of about 0.1 to about 0.2 percent.

[0065] This written description uses examples to disclose the invention, including the best mode, and also to enable any person skilled in the art to make and use the invention. The patentable scope of the invention is defined by the claims, and may include other examples that occur to those skilled in the art. Such other examples are intended to be within the scope of the claims if they have structural elements that do not differ from the literal language of the claims, or if they include equivalent structural elements with insubstantial differences from the literal languages of the claims.

What is claimed is:

1. A device for selectively controlling and varying surface texture comprising: